OBSERVATIONS OF CONDENSATION-NUCLEI IN THE ATMOSPHERE

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OBSERVATIONS

In the summer of 1933 the writer began a study of atmospheric condensation-nuclei with the small counter of J. Scholz (**1**). All observations discussed in this paper were made with the same instrument and by the same observer, and hence are comparable. Furthermore, in evaluating the observations all the precautions mentioned by Wait (**2**) for nuclei counters of the Aitken type have been taken.

The observations were made in four different districts: The first series, at the Taunus Mountain Observatory in Germany (800 m above sea level, 700 m above surroundings), comprised 700 sets of observations on 120 days (**3**); the second, at Koenigstein (500 m above sea level, 4 km southwest of the Taunus Observatory, on the slope of the mountain), 44 sets of observations on 10 days (**4**); the third, a short series of 7 sets of observations on 4 days (**3**), made while crossing the North Atlantic Ocean westward; and the fourth, 300 observations on 110 days in the late summer and fall of 1934, at State College (Pennsylvania), (360 m above sea level) in the Nittany Valley of the Allegheny Mountains.

SOURCES OF CONDENSATION-NUCLEI

We know from the fundamental investigations of H. Koehler (**5**) that many condensation-nuclei are sodium chloride crystals from the oceans. The amount of chlorine in rain water indicates that practically all condensation-nuclei in the higher levels of the atmosphere must be salt crystals, otherwise it would be very hard to account for the amount of chlorine in fog and rain water found by H. Kohler and recently also by H. Israel (**6**) and M. Bossolasco (**7**). Nevertheless the number of condensation-nuclei coming from the ocean is astonishingly small. Wigand, Bossolasco, and others stated this fact; and my observations on the North Atlantic Ocean show an average value of 950 No/ccm, with a maximum of 1,450 No/ccm, and minimum of only 150 No/ccm. These values are for the layer nearest the surface of the sea. As the number of nuclei decreases rather rapidly with altitude, even in case of considerable convection, and as it decreases probably also with distance from the ocean, and since we have, on the other hand, about 200 droplets/ccm in clouds, it is very difficult to account for all the nuclei necessary by salt crystals from the ocean. However, to account for the amount of chlorine in rain water we must either assume that the nuclei are larger by far than heretofore assumed (10^{-15}g), or that other sources of chlorine are present. This problem requires further investigation.

In settled countries by far the largest number of condensation-nuclei are due to combustion. Practically all products of combustion which occur in atmospheric suspension, except perhaps, only the larger soot particles, are condensation-nuclei. Factories, railways, house furnaces, and, by no means least, the combustion gases of motor cars, furnish the vast amount of condensation-nuclei which we find in the cities. This is clearly shown by the annual variation of the number of condensation-nuclei in or near populated districts. It is even to be seen in a small countryside town, such as State College, Pa. Figure 1 shows that the condensation-nuclei nearly doubled after the heating period started this fall, 1934. The same observation recently has been published by Egloff (**8**) for Davos. The ion countings of Wait and Torreson (**9**) at Washington, D. C., also show the same tendency. Clearly, then, the number of condensation-nuclei in settled regions gives us a fair picture of the suspended impurities in the air.

The third source of nuclei is the ultraviolet radiation of the sun, which forms large ions. We found as many as 500,000 No./ccm due to such ions near a mercury lamp, in agreement with L. Schulz (**10**). Although these are laboratory values it may be assumed that also in the free atmosphere a certain number of nuclei are due to ultraviolet solar radiation. This may be one reason for the variations of nuclei in unpopulated regions (cf. Hogg, **11**).

THE VARIATIONS OF NUCLEI

In the regions here under consideration, however, this last possibility may be neglected, as there are in these places far more potent factors. The largest local variation is due to the elevation. Wigand (**12**) has measured the distribution of nuclei with height by balloon ascents; but it is also possible to get very good results for the lower levels by motoring from a plain up to the top of a nearby mountain. This has been done several times by going from the top of the Taunus Mountain down to the industrial centers in the Main Valley near Frankfurt (Germany), which covers a difference of 700 m in height in a horizontal distance of 18 km. In the case of a wind blowing up-mountain, which should carry the largest amount of nuclei, it is found that on the top of the mountain only 10 percent of the number near the city is present. This normal distribution may be considerably changed by convection. Figure 2 gives the diurnal variation of nuclei on the slope and at the mountain station on bright days with considerable vertical convection, while a third curve represents the number at the mountain station on dull days without convection. Note that the convection current reaches the slope station about 2 hours earlier than the crest station. Others have shown that on the plain the course of nuclei is inverse (minimum at noon), and the ion observations of Wait and Torreson at Washington, D. C. (**9**) also indicate such a variation.

If the connection with other meteorological elements is examined, we find a fair correlation between the number of nuclei and the relative humidity. Figure 3 represents the results obtained at State College and at the Taunus Observatory. Both curves show decreasing numbers of nuclei with increase of relative humidity. That is reasonable, as many, principally the more hygroscopic, nuclei are surrounded by invisible water droplets before the saturation point in the air is reached, settle and thus escape counting (cf. Egloff l. c.).

Room experiments show that by hanging up wet sheets and thus increasing the relative humidity the number of countable particles is decreased by 50 percent in 1½ hours, while without this wetting the number remains nearly unchanged.

The next meteorological element investigated was the wind direction. Figure 4 shows the number of particles correlated to each wind direction at State College. Two

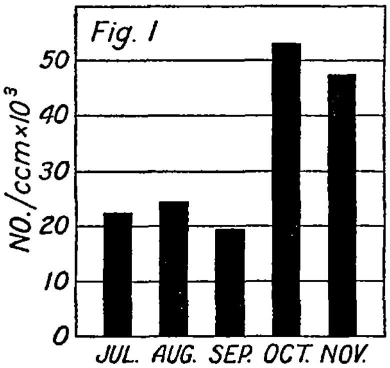
Fig. 1
NO./ccm×10³
0
10
20
30
40
50
JUL. AUG. SEP. OCT. NOV.

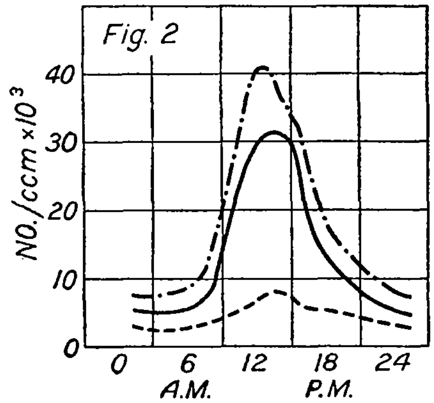
Fig. 2
NO./ccm×10³
0
10
20
30
40
0 6 12 18 24
A.M. P.M.

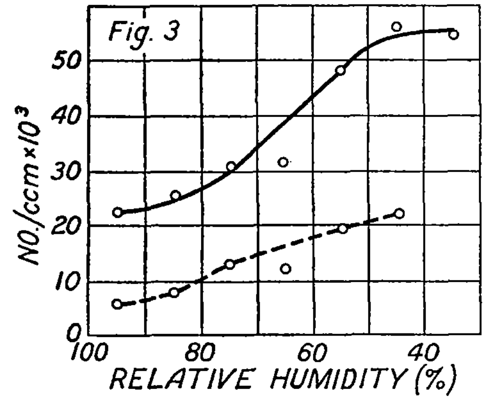
Fig. 3
NO./ccm×10³
0
10
20
30
40
50
100 80 60 40
RELATIVE HUMIDITY (%)

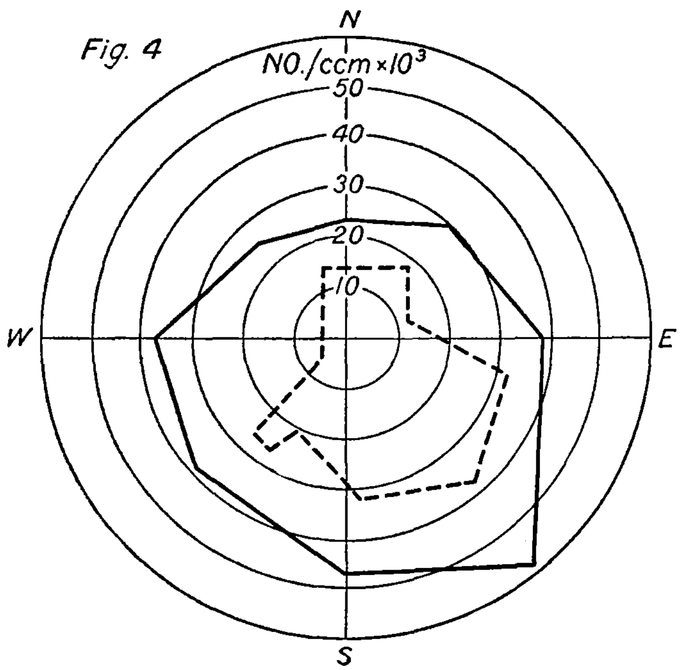
Fig. 4
N
NO./ccm×10³
50
40
30
20
10
W
E
S

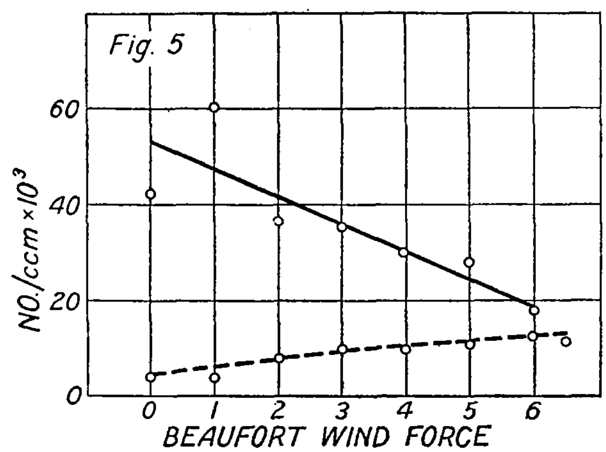
Fig. 5
NO./ccm×10³
0
20
40
60
0 1 2 3 4 5 6
BEAUFORT WIND FORCE

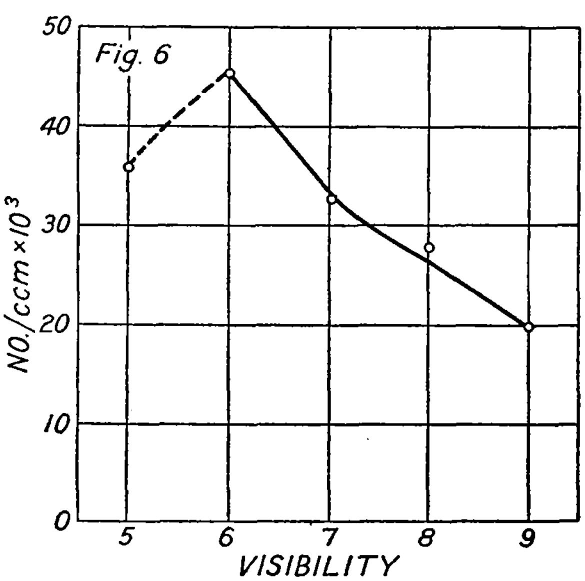
Fig. 6
NO./ccm×10³
0
10
20
30
40
50
5 6 7 8 9
VISIBILITY

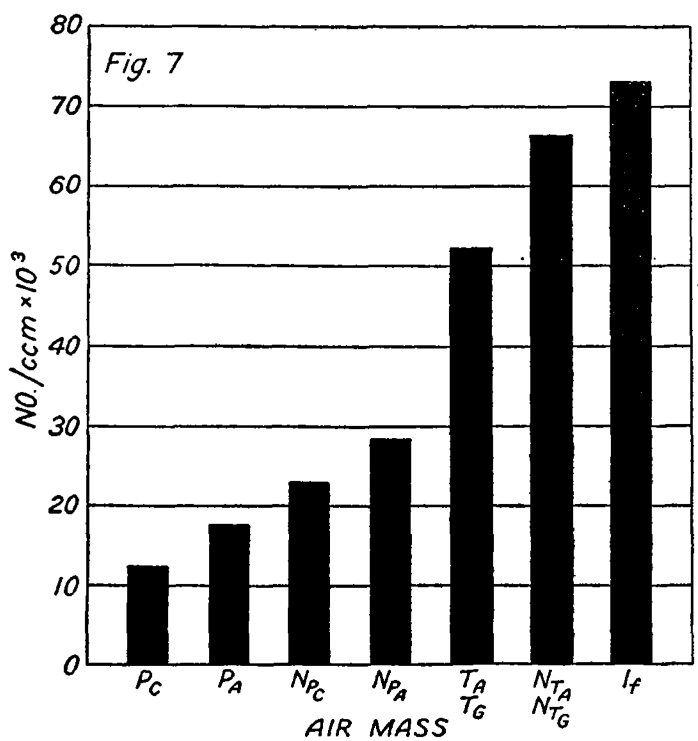
Fig. 7
NO./ccm×10³
0
10
20
30
40
50
60
70
80
P_C P_A N_{P_C} N_{P_A} T_A T_G N_{T_A} N_{T_G} I_f
AIR MASS

elements are here superposed. The influence of the location is shown by the dotted line which delimits the housed area in the vicinity of the observation place. The other element is the air mass which frequently is connected with one particular prevailing wind direction. The influence of the air mass will be discussed later.

The wind velocity shows also a certain influence on the number of nuclei. The graphs of figure 5 show this connection at a valley station like State College and at a mountain station. Both distributions can be approximated by straight lines with the equations:

$$\text{Taunus Mountain Observatory, } N_T = N_{T(c)} + 1200\ F$$

$$\text{State College, } N_s = N_{s(c)} - 8000\ F$$

where $N_{(c)}$ is the number per cubic centimeter at calm and F the wind velocity in Beaufort Scale divisions.

This means that at the higher level, increasing wind velocity brings an increasing number of nuclei. At the valley station it is just the opposite: increasing wind velocity is followed by a decreasing number of nuclei. This is due to the vertical mass transportation by turbulence, as the exchange coefficient increases with higher wind velocity.

Another well-known fact is that the visibility and the number of nuclei are connected; and, as we must expect, an increase of the impurity of the air decreases the visibility. This is shown by figure 6 for the values obtained at State College.

Finally the measurements at State College have been distributed according to air masses, which had generally been determined according to Willet **(13)**. The result is shown in figure 7. In many respects the impurities, represented by nuclei, give the same picture as has been found for turbidity factors by Wexler at Washington, D. C., **(14)** and Haurwitz at the Blue Hill Observatory **(15)**. In addition to the air masses given by Willet, it was thought desirable to specify another type of air mass called, according to the Linke system **(16)** in Europe, I, "indifferent." This type of air occurs frequently in high pressure areas, where air masses lose entirely their original properties and shift slightly back and forth. Usually it stays a longer time than do others in one area and it frequently is connected with subsidence of the air. This is indicated by the additional index of (foehn). The effect is the opposite of that of convection, and the number of particles near the surface increases steadily. That a surface of subsidence stops any diffusion of nuclei entirely was proved on the Taunus Mountain Observatory in two excellent cases, when the inversion subsided so that the station was first at the lower and later at the upper limit of the inversion. The number of nuclei was in the one case 2,200 per cubic centimeters below, and 110 above, that in the inversion; in the other case 4,000 and 300 respectively. Although it is difficult to separate the local influences from those of the air masses entirely, it is evident that an air mass change, even without shifting the wind direction, always brings a remarkable change in the number of condensation-nuclei. This holds even in cases of occluded fronts. Hence nuclear counts furnish one more method of identifying changes of air masses. Future investigations however will have to extend to the points of origin of air masses to get a more complete picture of the variation of the nuclei during the history of a particular air mass.

CONNECTED PROBLEMS

As just explained, nuclear counts may be helpful in air mass analysis, which is one of the major problems in modern meteorology. But another meteorological problem can be attacked also from this angle. Since convection and turbulence influence the vertical distribution of nuclei, therefore more exact values of exchange coefficients could be obtained by simultaneous measurements at a mountain and a nearby valley station. The above measurements taken in such different regions of the world would hardly be a sufficient basis for such calculations. The connection between vertical diffusion and wind, however, probably may be solved in this manner.

In addition to these purely meteorological problems, fuller information can also be obtained on the question of the connection between weather phenomena and human health. Dessauer, Strasburger, and Happel **(17)** have shown that some of the aerosol ions have distinct therapeutic influences. The writer's measurements of the amount of inhaled and exhaled nuclei show that in open air about 40 percent, and in room air about 25 percent, of the nuclei are absorbed by the respiratory tract. Observations of Amelung **(18)** point to the possibility of a kind of intoxication by ultra heavy ions. Another thing should also be mentioned in this connection: At the same time when the writer made the observations at the Taunus Observatory, a graduate student made observations of the emanation content of the atmosphere. These **(19)** show a striking parallel with nuclear counts. A rising amount of nuclei was connected with an increase of radioactive emanation. In the case of the one inversion mentioned above the emanation was 1.2×10^{-16} Curie/ccm below, and only 2.0×10^{-17} Curie/ccm above, the inversion. This and other considerations indicate that practically all emanation in the air is absorbed on nuclei. Following this suggestion, H. Israel **(20)** proved this relation to hold in a number of careful laboratory tests. This means that a certain amount of emanation will surely be retained in the human body by absorption of nuclei. The effects of inhaled emanation as an agent in the human body (be it therapeutic or pathogenic) is evident, and Gerke **(21)**, Aschoff **(22)**, Muck and collaborators **(23)** have established facts of this influence. Furthermore, Flach **(24)** has shown that many pathogenic weather effects are due to downward currents in the atmosphere or, as one may say, surfaces of subsidence. As shown above, such weather conditions increase the number of nuclei, and it is, perhaps, not too bold to infer a connection between these changes in the aerosol (nuclei, ions and emanation) and health. This may hold good also for the formation of the famous Belgium death fog with its stagnating air masses. Occasional observations of Petersen **(25)** on a group of patients with pollen sensitivity likewise seem to point to the same conclusion.

We are here just at the beginning of our knowledge, but some lines are drawn which may lead us to new results. If physicians and meteorologists attack this question in close collaboration a solution, increasing both our knowledge and human welfare, may be found.

SUMMARY

1. The results of 1,051 observations of condensation-nuclei at four different locations are given.

2. Connections between the number of nuclei and convection and turbulence are shown; and correlations between nuclear counts, relative humidity, visibility and wind are mentioned.

3. The relationship between nuclei contents and air mass is discussed, and the former found to be a valuable help in air mass analysis.

4. The effects of nuclei on human health, and their adsorption of radioactive emanation, principally with the occurrence of surfaces of subsidence, are discussed.

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PRECIPITATION IN THE NORTHERN GREAT PLAINS

By W. A. MATTICE

[Weather Bureau, Washington, January 1935]

Abnormalities in weather focus public interest on localities that may be experiencing unusual extremes. Thus, a report of extremely cold or hot weather in the newspapers at once arouses temporary interest in the place mentioned. Also, but to a more limited extent, local droughts are of interest, while floods occupy much space on the front page. Droughts usually are not so intensive in interest as floods, but the severe dry spells that were experienced in 1930 and again in 1934 were of such magnitude as to create wide-spread concern. The region covered in this paper has been the focal point of the droughts in recent years, as the precipitation in many places therein has been scanty for a comparatively long time.

Wide-spread interest has prompted this paper. The charts partially fill the need for detailed climatic maps of the area concerned. The data on which they are based are contained largely in Bulletin W, of the Weather Bureau.

Much comment has been heard in recent years about the suitability of our dryer regions for agriculture, and much of the Northwestern Plains has been classed as only semiproductive or submarginal. So far as temperature is concerned, many staple crops could be grown with profit in this section by selecting those with the proper thermal requirements, but the agricultural utilization of much of this land is limited by moisture conditions.

For ordinary agriculture the average annual precipitation is considered the limiting factor for general farming. However, the average or normal rainfall does not mean that this amount can be expected in 50 percent of the years, as it is generally well known that a greater proportion of the years have rainfall below normal.

Chart I shows the average annual precipitation for the northern Great Plains. In the preparation of this and other charts, the method of Kincer (1) was followed in locating the isohyetal lines. The average annual amounts range from around 25 inches, or slightly more, in southeastern South Dakota to less than 10 inches in parts of Wyoming and Montana. The annual rainfall decreases progressively westward, the region varying from semihumid in eastern South Dakota to almost arid in parts of Wyoming. The higher elevations of Montana and Wyoming are relatively well supplied with moisture, with the average annual precipitation over 30 inches in extreme western Montana and over 25 inches in north-central and northwestern Wyoming. On the other hand, parts of these States have less than 10 inches of rain a year, on the average, notably in the upper Red Rock Valley of Montana and in the lower Shoshone and Bighorn Valleys of Wyoming.

One important feature of this map is the large area with annual rainfall less than 15 inches. As the isohyetal lines are drawn to 2-inch intervals on the even numbers, some interpolation is necessary, but the size of the region can be readily determined. A large section of northwestern North Dakota has, on the average, less than 16 inches a year, while much of eastern and northern Montana has less than 14 inches. As the minimum amount of annual precipitation necessary for successful farming by ordinary methods usually is considered to be between 15 and 20 inches, this region is especially noteworthy. With an annual rainfall of less than 15 inches, other conditions must be very favorable to ensure successful farming in the long run.

In the Great Plains the agricultural significance of the rainfall depends principally on its seasonal distribution, the variations of amount from year to year, or its dependability, and the rate of evaporation. All of these modifying factors operate more favorably in the northern part than in other sections of the Plains, with the result that while rainfall is scantier in the north, conditions there are climatically more favorable for crop growth than elsewhere in the area where the average annual precipitation may be comparable.

In the Great Plains it is the rainfall of the crop growing season that is important from the agricultural viewpoint. The winter precipitation is light and the amount stored in the soil at the beginning of spring usually is small. Normally the rainfall increases rapidly with the advent of spring; May and June commonly are the months of greatest amounts. The warm-season rains comprise much the greater proportion of the annual, except in some districts of Montana.

Chart II shows the average warm season precipitation. This chart covers the months from April to September, inclusive. The amounts vary from around 20 inches in extreme southeastern South Dakota to less than 6 inches in north-central Wyoming. Much of South Dakota has more than 12 inches during this 6 months' period, while the eastern part of the State averages over 14 inches. In North Dakota the average amounts range from 11 to over 16 inches, but in Montana and Wyoming the topography has such a large effect that no definite extensive area can be delimited, except for eastern and northern Montana where the warm-season rainfall averages from 10 to 11 inches.